Liquid Thermal Conductivity of Binary Mixtures of Pentafluoroethane (R125) and 1,1,1,2-Tetrafluoroethane (R134a) 1

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ABSTRACT

Thermal conductivities of zeotropic mixtures of R125 (CF₃CHF₂) and R134a

(CF₃CH₂F) in the liquid phase are reported. Thermal conductivities have been measured

by a transient hot-wire method with one bare platinum wire. Measurements have been

carried out in the temperature range of 233-323 K and in the pressure range of 2-20 MPa.

The dependence of thermal conductivity on temperature, pressure, and composition of

binary mixture is presented. Measured thermal conductivity data are correlated as a

function of temperature, pressure, and overall composition of the mixture. The accuracy

of our measurements was estimated better than 2%.

KEY WORDS: mixture; R125; R134a; R125+R134; refrigerant; thermal conductivity;

transient hot-wire method

1. INTRODUCTION

CFC (chlorofluorocarbon) and HCFC (hydrochlorofluorocarbon) refrigerants have been recognized to have an influence on the depletion of the ozone layer and the global warming. The production and use of CFC refrigerants as working fluids in thermal systems has been strongly regulated, and the manufacturing of HCFC refrigerants will be controlled in the near future. HFC (hydrofluorocarbon) refrigerants such as R32, R125, R134a, R143a, etc. have been considered as environmentally acceptable refrigerants. In many cases, their binary or ternary mixtures are considered as alternatives in refrigerators, air conditioners, heat pumps, and chillers. Some of the refrigerant mixtures such as R32+R134a, R32+R125, R32+R125+R134a, etc., are believed promising working fluids and have been commercially produced. Many machine designers and engineers are testing the feasibility, durability, safety of using these refrigerant mixtures.

A number of measurements for the thermal conductivities of HFC refrigerants have been carried out by many researchers [1-6]. They have tried to establish property database from measurements and predictions. However, the experimental data for the thermal conductivities of HFC refrigerants are not sufficient. Particularly, there are very few thermal conductivity data for binary or ternary HFC refrigerant mixtures, so it is meaningful to get HFC mixtures' thermal conductivity data for the database enlargement, investigation of mixtures' thermal conductivity, and prediction model development.

In the previous papers, we have reported the measured data for single component HFC refrigerants (R32, R125, R134a) and binary HFC refrigerant mixtures (R32+R134a and R32+R125) [5, 6] in the liquid phase. Following our previous studies on the thermal conductivity measurement, the thermal conductivity data for HFC refrigerant mixture, R125+R134a, will be provided in this study for a wide range of temperature and pressure. The thermal conductivity in the liquid phase will be presented for several compositions of the refrigerant mixture.

2. EXPERIMENTS

In this study, the transient hot-wire method has been used in the measurements. The fundamental governing equations to determine the thermal conductivity of the liquid phase and the details of the apparatus together with the test procedures were described in our previous works [4-6]. Test apparatus is mainly composed of the hot-wire cell, pressure vessel and pressurizing device, electrical system with a Wheatstone bridge circuit, data processing system, and temperature control system. One bare platinum wire has been used to supply heat and to measure temperature change. The diameter and the length of the wire are 25 µm and 128.40 mm, respectively. The temperature of the bath in which the pressure vessel is submerged is kept at the specified temperature level with a temperature variation of ± 0.02 K. The data were taken over the time interval of 100 to 300 ms after starting current supply to minimize possible errors due to the natural convection in the hot-wire cell. The sampling frequency of our measurement is 2 kHz and the temperature rise during the measurement is about 1.5 °C. The purities of the sample refrigerants (R125 and R134a) supplied by Du Pont Company, are better than 99.8%. Before charging the sample refrigerants in the system, the system was evacuated for a long period of time and purged with the refrigerants to be filled in the system. The compositions of the refrigerant mixtures were analyzed by gas chromatograph.

Major inaccuracies of the experiment are attributed to several nonidealities [9-12]. However, we found that the measured temperature rise versus the logarithm of time was almost proportional for the time interval described above. The thermal conductivity data are analyzed for this period since it assures that the measurement is in accordance with its fundamental equation.

The thermal conductivity of toluene which is regarded as one of the standard liquids was measured before measuring the thermal conductivity of R125+R134a, to ensure the accuracy of our measurement. The data were found to agree within $\pm 1\%$ when compared with others' data [7, 8].

3. RESULTS

Measurements of the thermal conductivities of R125+R134a mixtures in the liquid phase have been carried out over the temperature range from 233.15 to 323.15 K (-40 to 50 °C) and the pressure range from 2 to 20 MPa. The mass fractions of R125 in the R125+R134a mixture were selected to be 0.1914, 0.3743, 0.5867, and 0.7850 to investigate the composition dependence of the thermal conductivity.

The measured thermal conductivity data for R125+R134a are listed in Table I. These values are the averages of five measurements under the same test conditions. The reproducibility of our measurement is within $\pm 0.5\%$. The thermal conductivities of R125+R134a when the mass fraction of R125 in the mixture is 0.5867 are plotted as a function of temperature in Fig. 1 and as a function of pressure in Fig. 2. As shown in Fig. 1 and Fig. 2, the thermal conductivity of R125+R134a in the liquid phase decreases as temperature increases, while the pressure has an opposite effect. Similar trend can be found for other compositions (see Table I). Fig. 3 shows the composition dependence of the thermal conductivity along isotherms for P = 10 MPa, and Fig. 4 shows the composition dependence along isobars for P = 10 MPa, and Fig. 3 and Fig. 4, the thermal conductivities for R125+R134a mixture are quite close to the mass fraction average of thermal conductivity data for pure R125 and R134a.

The experimental data for R125+R134a mixtures were correlated by the following polynomial equation in terms of temperature, pressure, and mass fraction of R125;

where is thermal conductivity in W·m⁻¹·K⁻¹, T is temperature in K, P is pressure in MPa and w is the mass fraction of R125 in the R125+R134a mixtures. The numerical values of all the coefficients in Eq. (1) are represented in Table II. In Fig. 5, the percentage deviations of the measured thermal conductivity data from Eq. (1) are shown. The root-mean-square deviation of the experimental data from Eq. (1) is about 0.5%.

4. CONCLUSION

Measurements of the thermal conductivities of R125+R134a mixture in the liquid phase are reported. The experiments were performed with a transient hot-wire method by changing temperature, pressure and composition of the mixture. The measurements were carried out in the temperature range from 233.15 to 323.15 K and the pressure range from 2 to 20 MPa. The measured thermal conductivity data of R125+R134a mixture are quite similar to the mass fraction average values of pure components' thermal conductivity data. The experimental results for the thermal conductivity of R125+R134a are correlated as a function of temperature, pressure and composition of the mixture. The average deviation of the measured thermal conductivity data from the values calculated by the fitting equation is about 0.5%. The overall accuracy of our measurement is better than 2%.

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Table I. Thermal conductivity of R125+R134a mixtures

T		T			Т]			Γ	
(°C)(W•	m-1•K-1)(00	C)(W•r	n-1•]	K-1)(°C)(W•m ⁻¹ •.	K-1)(°C))(W•m ⁻¹ •	K-1)(°C)	(W•m ⁻¹ •K ¹))
P=:	2.0 MPa	P=5	.0 M	IPa	P=10.0]	MPa	P=15.0 N	MPa	P=20.0 MI	Pa
		R1	25:]	R134a=	1.0000:0.	0000 (b	y mass)			
-41.6	0.0898-4	1.80.09	15	-41.9	0.0939	-41.9	0.0963	-41.6	0.0984	
-25.5	0.0812-25	5.40.08	30	-25.5	0.0858	-25.4	0.0882	-25.4	0.0910	
-0.5	0.0706 -0	.60.07	26	-0.6	0.0761	0.6	0.0793	-0.7	0.0821	
26.9	0.058526	.20.06	21	26.5	0.0659	27.1	0.0696	26.5	0.0734	
-	-	50.9	0.0	52450.	90.0584	50.8	0.0624	50.8	0.0661	
			R	125:R1	34a=0.78	350:0.21	50			
-40.3	0.0941-40	0.20.09	56	-40.2	0.0978	-40.2	0.0999	-40.30.1	019	
-25.3	0.0869-25	5.30.08	881	-25.5	0.0906	-25.3	0.0931	-25.40.0	953	
-0.4	0.0761-0.	.3 0.07	79	-0.2	0.0814	-0.3	0.0841	-0.40.08	366	
24.5	0.0647 24	1.80.06	79	24.7	0.0718	24.7	0.0750	24.70.0	781	
-	-	50.4	0.0	597 50	.00.0640	49.9	0.0679	49.90.0	712	
R125:R134a=0.5711:0.4289										
-40.8	0.0967-40	0.70.09	84	-40.6	0.1006	-40.7	0.1031	-40.6	0.1047	
-25.6	0.0906-25	5.60.09	18	-25.7	0.0945	-25.5	0.0969	-25.8	0.0992	
-0.5	0.0797-0.	5 0.08	17	-0.6	0.0851	-0.4	0.0879	-0.5	0.0904	
24.4	0.068824	.50.07	18	24.5	0.0752	24.6	0.0786	24.5	0.0818	
-	-	49.7	0.0)62149.	80.0670	49.9	0.0704	50.4	0.0739	

Table I. Thermal conductivity of R125+R134a mixtures (continued)

Т	T		Т	,	Γ	ı	Т	
$({}^{o}C)(W \bullet m^{-1} \bullet K^{-1})({}^{o}C)(W \bullet m^{-1} \bullet K^{-1})({}^$								
P=2	2.0 MPa P=5.0 M	I Pa	P=10.0	MPa	P=15.0 M	IPa	P=20.0 MPa	
	R	R125:R1	.34a=0.37	'43:0.62	.57			
-40.4	0.1031-40.30.1047	-40.2	0.1067	-40.2	0.1087	-40.2	0.1111	
-25.5	0.0960-25.20.0979	-25.3	0.1002	-25.4	0.1026	-25.5	0.1046	
-0.2	0.0851 -0.30.0871	-0.3	0.0900	-0.2	0.0930	-0.2	0.0956	
24.8	0.0748 24.70.0774	24.9	0.0806	24.9	0.0836	25.0	0.0867	
49.9	0.0647 50.10.0674	49.9	0.0718	50.1	0.0752	50.1	0.0786	
	R125:R134a=0.1914:0.8086							
-40.4	0.1071-40.40.1085	-40.2	0.1105	-40.4	0.1125	-40.3	0.1143	
-25.1	0.1000-25.00.1012	-25.2	0.1036	-25.2	0.1059	-25.1	0.1081	
-0.2	0.0891 -0.20.0911	-0.2	0.0938	-0.2	0.0966	-0.2	0.0991	
24.6	0.0786 24.60.0805	24.8	0.0839	24.9	0.0878	25.0	0.0906	
50.1	0.0687 50.10.0709	50.2	0.0747	50.2	0.0785	50.3	0.0816	
R125:R134a=0.0000:1.0000								
-40.4	0.1109-40.40.1123	-40.4	0.1145	-40.2	0.1165	-40.4	0.1184	
-25.5	0.1041-25.50.1055	-25.1	0.1081	-25.4	0.1104	-25.3	0.1122	
-0.3	0.0939 -0.20.0957	-0.4	0.0986	-0.4	0.1009	-0.1	0.1032	
24.9	0.0830 25.10.0851	24.7	0.0885	24.7	0.0917	24.9	0.0944	
49.7	0.0723 49.80.0751	49.8	0.0787	50.1	0.0824	50.1	0.0855	

Table II. Coefficients in Eq. (1) for R125/R134a mixtures

0	2.103697×10 ⁻¹						
	k=0	k=1	k=2				
a _{00k}	1.000000×10^{0}	7.209919×10 ⁻¹	-6.183520×10 ⁻¹				
a_{01k}	4.849657×10^{-3}	-6.703170×10 ⁻²	7.872269×10 ⁻²				
a_{02k}	-1.293985×10 ⁻⁴	1.869815×10 ⁻³	-2.360631×10 ⁻³				
a_{10k}	-2.043133×10 ⁻³	-6.100480×10 ⁻³	4.636145×10 ⁻³				
a_{11k}	-3.108052×10 ⁻⁵	4.661615×10 ⁻⁴	-5.715948×10 ⁻⁴				
a_{12k}	8.273776×10 ⁻⁷	-1.243560×10 ⁻⁵	1.680477×10 ⁻⁵				
a_{20k}	-4.109788×10 ⁻⁸	1.113836×10 ⁻⁵	-8.660620×10 ⁻⁶				
a_{21k}	8.901141×10 ⁻⁸	-8.002610×10 ⁻⁷	1.037339×10 ⁻⁶				
a _{22k}	-1.570988×10 ⁻⁹	2.044185×10 ⁻⁸	-2.990036×10 ⁻⁸				

FIGURE CAPTIONS

- Fig. 1 Measured thermal conductivities of R125+R134a mixtures; temperature dependence along isobars when mass fraction of R125 is 0.5867.
- Fig. 2 Measured thermal conductivities of R125+R134a mixtures; pressure dependence along isotherms when mass fraction of R125 is 0.5867.
- Fig. 3 Measured thermal conductivities of R125+R134a mixtures; composition dependence along isotherms for P = 10 MPa.
- Fig. 4 Measured thermal conductivities of R125+R134a mixtures; composition dependence along isobars for T = 0 °C.
- Fig. 5 Percentage deviations of the experimental thermal conductivities from Eq. (1) for R125+R134a mixtures.

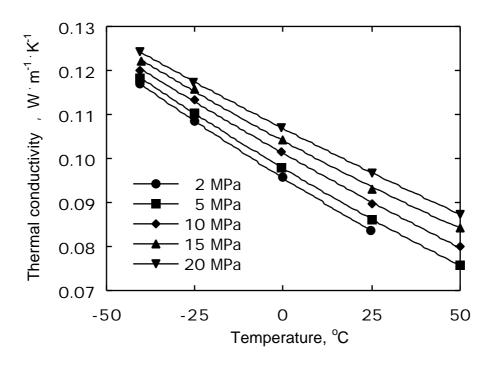


Fig. 1

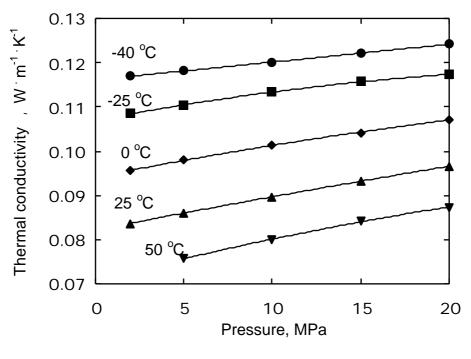


Fig. 2

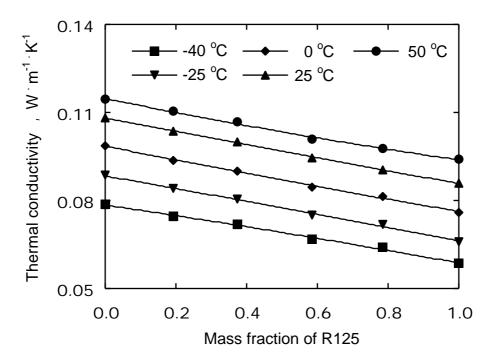


Fig. 3

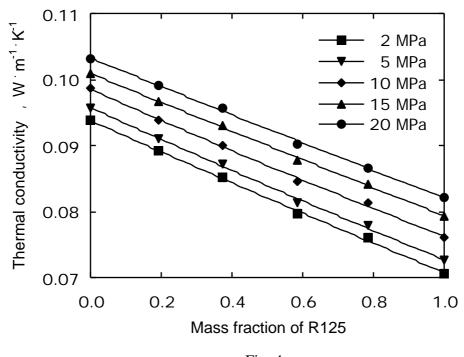


Fig. 4

